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Principles of Rest-Rotation Grazing and Multiple-Use Land Management

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U.S. DEPARTMENT OF THE INTERIOR
Bureau of Land Management

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The author developed rest-rotation grazing management principles, as now practiced, during his 36 years of service with the Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture. Since transferring to the Bureau of Land Management, U.S. Department of the Interior, in 1966, as a range management advisor, he has been active in the area of range management training to public land managers, livestock operators and others.

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FOREWORD

This publication highlights a course in range management that I have given to the Forest Service, U.S. Department of Agriculture, the Bureau of Land Management, U.S. Department of the Interior, and other interests at various times since 1963. The material was prepared especially for public range managers and stockmen, but should prove of value to anyone concerned with the use and management of wildlands. I have placed special emphasis on rest-rotation management of grazing.

For their many suggestions for improving this publication, I am grateful to Drs. Edward C. Stone and Paul Zinke of the School of Forestry and Conservation, University of California; and to the following personnel of the Forest Service: Reginald M. DeNio, Division of Range Management, and Kenneth W. Parker, retired, formerly Division of Watershed, Recreation, and Range Research, Washington, D.C.; John S. Forsman, Range and Wildlife Management, Region 6, Portland, Oregon; and James P. Blaisdell, Range Management and Wildlife Habitat Research, Intermountain Forest and Range Experiment Station, Ogden, Utah.

Readers who wish further information on the major topics discussed in this publication should consult the list of selected references on page 25.

Principles of Rest-Rotation Grazing and Multiple-Use Land Management

INTRODUCTION

About 728 million acres of wildland west of a line south from Canada through North and South Dakota, Nebraska, Kansas, Oklahoma, and Texas make up what is commonly called the western range. Grazing management is discussed in this publication in relation to ranges in this area.

The western range is semiarid. Annual precipitation averages about 15 inches for the entire area. But in some localities, it averages less than 5 inches; in others, more than 60 inches. In some areas precipitation falls mainly in winter and in others mainly in summer; generally, winters are cold and snowy, summers are warm and dry. Topography varies from gentle, nearly flat to rough mountainous. Livestock ranges extend from sea level to altitudes of 12,000 feet.

This range area is covered by grassland, shrub, and tree types (table 1). The vegetation consists mainly of perennial plants, although annuals are abundant in some places. The vegetation provides excellent forage for livestock and also food and cover for a variety of wildlife, including such big game as deer, elk, and antelope. Cattle and sheep are the principal kinds of livestock grazed. The land also yields water, timber, recreation, and other values all of great importance to the people of the country. Sustained high-level production of these many values is vital to the Nation.

Table 1.—*Plant types on the western range*[1]

Type	Acres	Percent
Tall grass	18,513,000	2.5
Short grass	198,092,000	27.2
Pacific bunchgrass	42,534,000	5.8
Semidesert grass	89,274,000	12.3
Sagebrush grass	96,528,000	13.3
Southern desert shrub	26,896,000	3.7
Salt-desert shrub	40,858,000	5.6
Pinon-juniper	75,728,000	10.4
Woodland-chaparral	13,406,000	1.8
Open forest	126,367,000	17.4
Total	[2]728,196,000	100.0

[1] U.S. Dep. Agr. The western range. 1936.

[2] Does not include dense forest, barren or inaccessible areas, or areas from which livestock grazing is excluded, such as national parks, military reservations, and municipal reservoir sites.

About half the range area is privately owned (table 2). About 7 percent is Indian land. The rest is publicly owned and administered by Federal, State, county, and municipal agencies.

The Forest Service and Bureau of Land Management administer about 29 percent of the total rangeland acreage—the former about 88 million acres and the latter about 128 million acres. The management goals of these agencies are prescribed by law: Public Law 86–517, June 12, 1960, guides the Forest Service, and Public Law 88–607, September 19, 1964, the Bureau of Land Management. The essence of these laws, commonly called multiple-use laws, is expressed in the following excerpts:

> Lands shall be administered for livestock grazing, timber, watershed, wildlife, fish and recreation purposes, and for preservation of public values under principles of multiple use and sustained yield production.
>
> Multiple-use means: Management of all the various renewable surface resources of the land so that they are utilized in the combination that will best meet the needs of the American people—with consideration being given to the relative values of the various resources and not necessarily the combination of uses that will give the greatest dollar return or the greatest unit output.
>
> Sustained yield of the several products and services means the achievement and maintenance in perpetuity of a high-level annual or regular periodic output of the various renewable resources of the land without impairment of the productivity of the land.

Thus, the management objectives of these two agencies are sustained, high-level, regular, periodic output of the various renewable resources of the land. These are desirable objectives on all rangelands whether privately or publicly owned.

Much of the western range, however, has been deteriorated in the past hundred years. The productivity of the land has been reduced by both livestock and big-game grazing, fires, insects, rodents, plant diseases, weather, and a host of man's activities. Many desirable plants have been killed out

Table 2.—*Ownership of western rangelands*[1]

Ownership or control	Acres	Percent
Private	375,546,000	52
Indian	48,391,000	7
Federal:		
National Forests (Forest Service)	87,954,000	12
Public domain (Bureau of Land Management)	127,792,000	17
Other	22,997,000	3
State, county, and other	65,516,000	9
Total	728,196,000	100

[1] U.S. Dep. Agr. The western range. 1936.

and replaced by inferior ones. The plant cover has been thinned in most places, causing erosion and loss of soil fertility. It is estimated that grazing capacity for livestock has been reduced by half or more. Heavy stocking and long seasons of use by livestock year after year have been major factors in deterioration of the range.

Management must recognize that all renewable rangeland values stem directly or indirectly from vegetation. Sustained high-level production of these values therefore depends on proper management of the vegetation. The principal tool the rangeland manager has for managing vegetation is livestock grazing. It is the only force under firm control of the manager that can be applied on practically the entire range area.

Livestock grazing is desirable, if not essential, on rangelands for several reasons. A large portion of the vegetation on rangelands can be converted to more useful products only by livestock. As the Nation's population grows, an increasingly greater portion of its meat supply will have to be produced on rangelands. Arable lands will be used more and more to produce grain, vegetable, and fruit crops for human consumption. Furthermore, desirable vegetation and the overall productive capacity of rangelands can be increased more rapidly with livestock grazing than without. Livestock can be used to perform many important functions that can be achieved no other way over the entire or major portion of the range. They can be used to trample seed into the soil thereby promoting more forage and a better soil cover; to remove stifling old growth on plants, thus increasing plant vigor and production of usable herbage; to stimulate adventitious growth and higher quality forage; and to reduce fire hazard.

The biological facts for development of sound grazing methods have been known for a long time. As far back as 1914, A. W. Sampson outlined many principles of good grazing management. However, relatively little use has been made of these facts and principles. Reluctance to relinquish certain established ideas on management, even though proved ineffective in practice, has been a major deterrent to the development and use of better grazing methods.

Much of this publication is devoted to a review of some of the more important facts on which good grazing management is based. The use of this information in formulating effective grazing methods is described.

THE PLANT

Production and maintenance of vegetation are of first consideration in management. Ranges are deteriorated because plants are killed. The ground space so vacated is taken over by other, usually less desirable plants—or remains bare and subject to erosion. The main problems of grazing management on western ranges center on perennial plants—particularly those that reproduce from seed. Management that maintains these plants invariably maintains plants that reproduce vegetatively. An understanding of why plants are killed by grazing is essential for development of satisfactory grazing methods and maintenance of the range resource.

Plants, like animals, require food for growth and sustenance. The food materials used for these purposes are carbohydrates, proteins, and fats. Animals obtain these substances by eating plants or other animals. Plants manufacture these substances; in other words, plants make their own food.

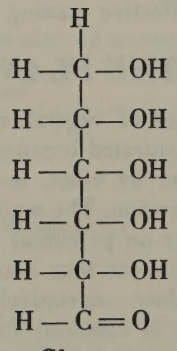
The plant first produces sugar glucose in the process of photosynthesis. Using this sugar as a building block, it then makes all the other food materials. Glucose is formed only in green cells and, principally, in leaves. The other compounds can be made anywhere in the plant, in the top or roots, or in green or nongreen cells. But because glucose is the basis of all food materials, the plant may be said to make its food in its green leaves.

In perennials, some of the food materials made by the plant each year are stored for future use. Carbohydrates, proteins, and fats are all stored, but the bulk of the material is starch. In herbaceous perennials, the materials are stored in roots and other underground parts and stem bases. In woody plants, they are stored above ground in stems, branches. twigs, and leaves as well as in underground parts. Some of these reserves are used to start growth in spring and to nourish the plant when it is not making food—in winter, for example, when the plant is dormant. Reserves are replenished regularly in normal growth.

Perennials store enough food to last for several years. So even if the plant is defoliated, as by grazing, for a year or two, it does not die. Under continuous close grazing year after year during the green period, however, the plant cannot make and replenish reserves. Consequently, reserves are ultimately depleted and the plant dies. As in the case of an animal, the plant becomes progressively weaker and smaller as it runs out of food. It can, in fact, starve to death.

PHOTOSYNTHESIS

Glucose ($C_6H_{12}O_6$; see structural formula below) is formed in the living cell from carbon dioxide gas (CO_2) and water (H_2O) in the presence of the green pigment chlorophyll ($C_{55}H_{72}O_5N_4Mg$) and sunlight in the process of photosynthesis. Oxygen gas (O_2) and water are generated as glucose is formed.



Glucose

The chemical reaction of photosynthesis may be written as follows:

$$6CO_2+12H_2O \xrightarrow[\text{Chlorophyll (green)}]{\text{Sunlight}} C_6H_{12}O_6+6O_2 + 6H_2O \quad (\text{stored energy})$$

Photosynthesis takes place in the chloroplasts of the cell. Chloroplasts are green because of the presence of chlorophyll. The carbon dioxide used in photosynthesis is obtained from the atmosphere; the water, from the soil; and the energy used to drive the process, from sunlight.

Chlorophyll traps and converts sunlight energy into work energy in the cell. A portion of this energy is then used to disintegrate carbon dioxide and water into essentially atom units and to reassemble these units in the form of glucose, oxygen gas, and water. Another portion is stored in glucose as it is produced. And a further portion is stored temporarily in special phosphorus-containing compounds. This latter energy is ultimately incorporated in other organic compounds as they are formed or is expended in work.

Thus, photosynthesis is an energy-storing process. The energy derived from sunlight is stored in the bonds connecting atoms in molecules. This energy is released when the molecules are disintegrated and the bonds broken. The energy contained in all food materials is derived through photosynthesis and is released when the materials are utilized.

Essentially then, the plant can make food only when it is green. The amount produced is controlled by such factors as light intensity, temperature, availability of water and soil minerals, and amount of chlorophyll in the plant, which is related to the size of the green plant. Some of these factors, such as availability of water and minerals and size of the green plant, are affected by grazing, and can be controlled by the range manager.

COMPOSITION OF FOOD MATERIALS

Carbohydrates

The more important carbohydrates in the plant from the standpoint of growth are the three sugars—glucose, fructose, and sucrose—and starch, inulin, and cellulose. All these compounds, except cellulose, are prime sources of energy and growth materials for the plant. Cellulose is a structural material and is not usually broken down once it is formed.

Fructose (fruit sugar) is a 6-carbon sugar-like glucose and is formed from it. These sugars have the same chemical formula, but the molecules differ structurally. Phosphorus is essential for conversion of glucose to fructose, in fact, it is essential for the formation of glucose and all carbohydrates.

Sucrose (beet or cane sugar) $C_{12}H_{22}O_{11}$ is formed by the union of one molecule of glucose with one molecule of fructose.

Starch makes up the bulk of the food reserves in plants. It occurs in cells in the form of starch grains. It consists of long, often branched, spiral chains of glucose molecules linked together. A molecule of water is eliminated from

between each two adjoining glucose units as starch forms. It is a partially dehydrated compound and, because it is relatively insoluble, it makes a good storage material.

Inulin is like starch and is used in the same way. It consists of chains of fructose units rather than glucose units.

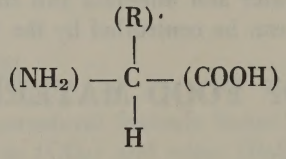
Cellulose is the main component of the cell wall. It consists of long, straight chains of glucose molecules. The chains are bound together in cable-like strands of varied size which are interwoven in the cell wall to form a porous framework. In mature cell walls, the spaces between cellulose strands are characteristically filled with lignin and relatively insoluble carbohydrates. These materials strengthen the wall and make it largely impervious to water. Cellulose forms the bulk of the roughage in forage plants and feedstuffs.

Proteins

Proteins make up most of the living material in cells. A yellowish viscid substance, protein looks like raw egg white. Most of the protein in the plant is enzymatic, but some is inert and comprises food reserves. Proteins are concentrated in buds, root tips and other meristematic tissues, terminal portions of twigs, and seeds.

Proteins contain nitrogen and sulfur in addition to carbon, hydrogen, and oxygen. The molecules consist of long chains of amino acids and are large and tremendously complex.

Amino acids are characterized by the presence of an amino radical (NH_2), and an acid radical (COOH), in the molecule. The general formula for an amino acid may be written as follows:



Twenty-two amino acids are known to occur in plant proteins. They differ from each other by the arrangement of chemical elements in the (R) group. The simplest amino acid is glycine in which the (R) group is a hydrogen atom.

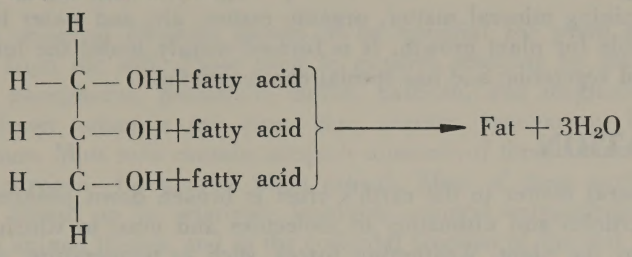
Proteins differ from each other mainly in the number, kind, and arrangement of amino acids in the molecule. Some proteins contain all 22 amino acids, some less. Proteins, like all organic compounds, contain energy—but somewhat less energy than carbohydrates and fats.

Fats

Fats (or oils) occur in small amounts in all plant cells. They play vital roles in the cell. Fats occur in large amounts in the stems and twigs of some shrubs and trees, especially in winter, and also in some seeds. Fats contain large amounts of energy.

Fats and oils are the same chemically but differ physically. In general, fats are solid at room temperature, oils are liquid.

Fats are formed by the union of glycerol and certain organic acids, known as fatty acids, as shown below:



(glycerol)

Some of the more abundant fatty acids are oleic, lauric, myristic, palmitic, stearic, linoleic, and linolenic. Fats differ from each other in the kinds of fatty acids in the molecule. The acids in the three positions may be the same or different.

RESPIRATION

Respiration is an oxidation or burning process that requires gaseous oxygen. It is essentially the reverse of photosynthesis. The energy stored in organic compounds during photosynthesis is liberated in respiration. The initial breakdown of organic materials is accomplished by enzymes. Starch may be reduced to glucose units, sucrose to glucose and fructose, proteins to amino acids, and fats to glycerol and fatty acids. These units may be reduced even further and then reassembled into new compounds. Carbohydrates, proteins, and fats can all be interconverted this way. Or the ultimate units may be degraded to carbon dioxide and water with the liberation of large amounts of energy. Gaseous oxygen is required in this final step. The chemical formula for respiration, using glucose as an example of an organic compound, may be written as follows:

$$C_6H_{12}O_6 + 6O_2 \longrightarrow 6CO_2 + 6H_2O + \text{Energy}$$

Respiration is continuous. Food materials are burned and energy liberated continuously even when the plant is dormant. Reserves can, therefore, be depleted by respiration alone.

To grow normally, the plant must contain adequate food materials to burn and adequate gaseous oxygen to effect burning. Vigorous growth depends on a high level of reserves in roots and a well aerated soil.

SOIL

Soil is the basic land resource and must be protected at all costs. Soil is renewable and will regenerate if destroyed, but this process may take hundreds, if not thousands, of years. Land productivity depends on soil

fertility. On rangelands, fertility is lost mainly through erosion. It is maintained by keeping a maximum protective cover of vegetation and organic litter on the soil.

Soil may be defined as a thin decomposing layer on the surface of the earth containing mineral matter, organic matter, air, and water in proportions suitable for plant growth. It is formed mainly under the influence of climate and vegetation and has special characteristics.

FORMATION

The mineral matter in the earth's crust is broken down progressively to smaller particles and ultimately to molecules and ions, in which forms it is usable by the plant. Weathering forces, such as temperature, water and wind, gravity, and chemical interactions, decompose the minerals. Low forms of plant and animal life, such as bacteria, algae, fungi, and protozoa, grow in the soil as soon as mineral decomposition begins. Later, higher forms grow—plants with large root systems and such animals as insects, worms, and rodents ultimately become abundant.

Plants and animals play important roles in soil formation. When these organisms die and decompose, humus is formed in the soil. Humus is a residue of organic matter decomposition. It consists of relatively decay-resistant materials, such as lignin, waxes, fats, and microbial cells. It is nearly black and darkens the soil.

As soil forms, it tends to differentiate into two horizontal layers: the *A* or upper horizon and the *B* or lower horizon. These two horizons differ in color and in physical and chemical properties. Horizon *A* tends to be darker because of greater concentration of humus. Most humus is derived from plant roots which are concentrated in the upper portion of the soil. Horizon *A* also tends to become loamy. Some of the finer mineral particles in the upper portion of the soil are carried down to lower depths by water and deposited and so horizon *B* tends to be clayey.

The effects of weather and plant and animal influences decrease as depth below the ground surface increases. Any effect is ultimately neutralized. Hence soil forms only to a certain depth. It rests on the parent mineral matter which may be solid rock or fine material such as sand or silt.

A soil with well developed horizons may take several thousand years to form. A soil is said to be young while the horizons are developing and mature or old when the horizons are well defined. In arid regions the horizons may not become clearly evident because of limited rainfall and vegetation and high oxidation rate of organic matter.

If destroyed by erosion, a soil will re-form because conditions for soil formation are ever present. In a sense, a soil is made younger by erosion. Thus, a soil may be viewed as a living mass capable of regeneration.

FERTILITY

The fertility of a soil is determined by the availability of mineral elements and water to the plant and such factors as aeration, and degree of acidity or alkalinity of the soil.

Twelve chemical elements known to be essential for plant growth are obtained from the soil. Those used in greatest amounts by the plant are nitrogen, phosphorus, potassium, sulfur, calcium, and magnesium. Those used in lesser amounts are iron, zinc, copper, manganese, boron, and molybdenum. Most soils contain adequate amounts of these elements—except possibly nitrogen—for normal plant growth. Most of these nutrients, however, are bound up in relatively insoluble mineral compounds, in living plant and animal tissues, and in the colloidal fraction of the soil. Therefore, they are not immediately available to the plant. Only nutrients in the soil solution in molecule and ion form are immediately available.

Organic Matter

The availability of minerals and other soil characteristics that influence soil fertility are governed largely by soil organic matter. When plants and animals die and decompose, a large supply of nutrients is released into the soil in a form readily used by the plant. Organic matter increases the moisture-holding capacity of the soil and therefore the amount of nutrients that can be held in solution and made available to the plant. Several different acids are generated in the soil as a result of respiration and decomposition of organic matter; the most important is carbonic acid. These acids speed the solution of nutrients from mineral matter and also promote the availability of nutrients held on colloidal particles in the soil.

Colloidal particles are of two types: mineral and organic. Mineral colloids are essentially small bits of clay, and organic colloids, small bits of humus. These particles are negatively charged and attract and hold positively charged ions including hydrogen ions. Hydrogen ions have a strong tendency to displace other ions and to put them into the soil solution. Important nutrients, such as calcium and magnesium, are relatively easily displaced.

Organic colloids are formed more rapidly and are much more dynamic in storing and making nutrients available to the plant than mineral colloids. The affinity of colloidal particles for hydrogen and other positively charged ions tends to reduce active acidity and alkalinity of the soil solution to a narrow range. Organic matter promotes a granular soil structure and increases water percolation and soil aeration. It lightens a heavy soil and binds a light one.

Nitrogen

Nitrogen, used in large amounts by the plant, is readily leached from the soil. It is more likely to become deficient than any other mineral nutrient.

Higher plants use nitrogen mainly in the form of nitrate ion, NO_3. They cannot use atmospheric nitrogen. They absorb nitrate from the soil. However, nitrate does not occur in appreciable amounts in rock minerals, but is produced in the soil from atmospheric nitrogen through the action of bacteria.

Two types of bacteria can change gaseous nitrogen (N_2) to amino form (NH_2) and incorporate it into protein in their bodies. One type lives in nodules on the roots of a host plant—such as legume. The other type lives free in the soil independent of a host. Both types fix mineral nitrogen in organic matter.

When nitrogen-fixing bacteria die, the protein nitrogen in their bodies is converted to ammonia (NH_3) by other bacteria. Ammonia is then changed first to nitrite ion (NO_2) and then to nitrate ion (NO_3) by still other kinds of bacteria. Thus, nitrogen is converted to a form usable by the plant. The energy used by bacteria for this conversion is derived mainly from carbohydrates in plant roots. Maximum food is provided bacteria when the roots are laden with food reserves.

Soil fertility, therefore, is maintained or increased by growing a maximum cover of vigorous plants on the land. Maximum production of plants is a prime objective of multiple-use rangeland management. Perennials—especially such fibrous-rooted ones as grasses—are superior to annuals for building and maintaining soil fertility because of their larger and deeper penetrating root systems.

HOW PLANT COMPOSITION CHANGES

The species composition of the vegetation changes continuously. It changes slowly in natural succession but may change rapidly under the influence of destructive forces such as grazing or fire.

In natural succession one association of plants after another, from low to high forms, grows on a site as the soil develops to maturity. Fundamentally, one association of plants succeeds or replaces another because the soil changes. Changes in vegetation, therefore, occur either as soil develops or as it is degraded through erosion.

Rate of natural succession is correlated with rate of soil development and so is slow. One association of plants may not succeed another for hundreds, if not thousands, of years.

The plant association that establishes on the mature soil is called the climax association. It is the most stable and long-lived plant group because the soil is stabilized. The tendency in natural plant succession is for development of the climax association.

The plant composition may be changed relatively quickly in a matter of only a few years by improper grazing. Initial changes in composition result from selective grazing of plants by animals. Further changes may then occur because of soil erosion.

The tendency is for tap-rooted plants to become established on eroded sites. Such plants can grow on very young soils—even solid rock—and erosion makes a soil younger. On millions of acres of grassland sites where soil had developed to the point of supporting fibrous-rooted and rhizomatous plants, the rangeland is now dominated by tap-rooted plants because of soil erosion induced by grazing and other destructive forces. Some such plants are: sagebrush, rabbit brush, snakeweed, creosote bush, mesquite, juniper, and pinyon pine. In general, these plants are less desirable for grazing and other uses than the plants they replaced.

The composition of the vegetation on a given site is controlled mainly by the condition of the soil. Rate of improvement of the composition is determined by the degree of soil degradation and by the competition between existing and invading plants for occupancy of the site. Even under ideal management of grazing, improvement of the range will be slow where the soil has been eroded appreciably.

PLANT GROWTH

The seasonal growth and development of perennial plants is illustrated here with Idaho fescue (fig. 1). The growth pattern of this bunchgrass applies to other grasses and similar plants and to forbs and woody plants as well. Shoot growth of herbaceous plants and twig growth of woody plants are comparable. Plant growth stage is best expressed in terms of percentage growth and greenness of the shoot.

The elapsed time from start of growth to dormancy in Idaho fescue is 6 or 7 months. Shoot growth is completed in about 4 months. The plant loses greenness over a comparable period. The moisture content of the plant starts declining about the time the plant is half grown and starts slowing in growth. The total weight of the shoot declines late in the season because seeds shatter and plant parts dry out and disintegrate.

(The period of growth and development of different species on different sites may differ appreciably from that for this species. Some plants dry completely or shed leaves as they become dormant.)

Roots start growth before the shoot. Root growth is largely completed by the time the shoot is half grown. By then the plant is growing most rapidly and presumably has greatest need for a fully developed root system.

Approximately one third of the roots die each year. They start to die about the time root growth ends. A large amount of organic matter gets into the soil each year this way.

REGROWTH

Potential for the plant to regrow during the season is highest early in the season, and declines with advance of the season as soil moisture and the growth impetus of the plant decline (table 3). After the plant is half grown and starts slowing in growth rate, its regrowth is negligible. Grasses may

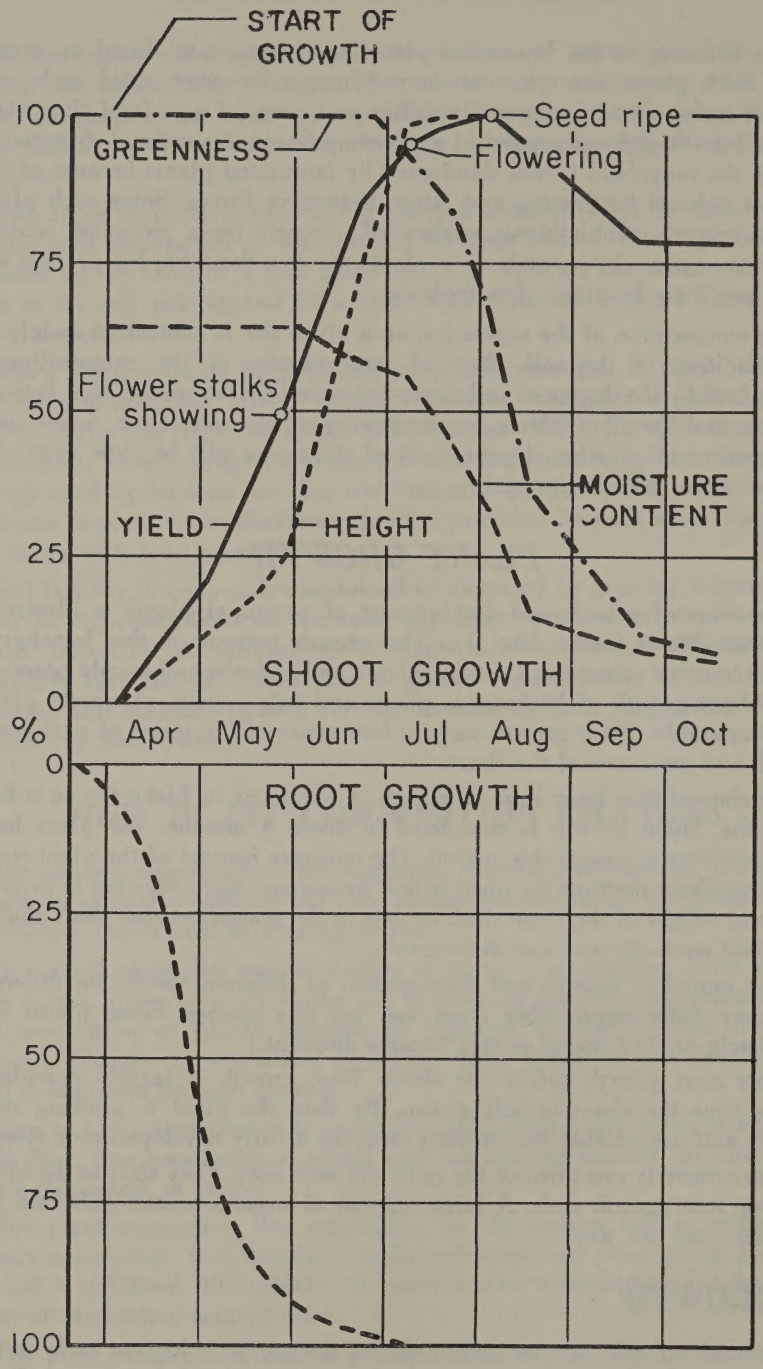


Figure 1.—Average seasonal growth and development of Idaho fescue. Shoot growth, based on data by Hormay and Talbot (1961), and general curve for root growth, based on information by Troughton (1957).

regenerate practically a full-size crown and produce appreciable viable seeds if defoliation or grazing is ended before the plant starts growing rapidly—before flower stalks are tall enough to be removed. Several weeks of grazing may be provided up to this time.

The combined yield of initial growth and regrowth from plants clipped early in the growing season is less than the yield of growth from unclipped full grown plants (table 3). Therefore, herbage production and grazing capacity during the season are reduced by early grazing. The amount of reduction is discussed later in the section on season of grazing.

Table 3.—*Yield of initial growth and regrowth of Idaho fescue clipped one to a 1.5-inch stubble at different growth stages; regrowth harvested when full grown*

Average date and growth stage at time of initial clipping	Initial growth	Regrowth	Initial growth and regrowth combined	
	Grams	*Grams*	*Grams*	*Percent*
May 1: Leaves about 3 inches tall	0.78	0.70	1.48	60
May 13: Flower stalks low in boot	1.09	.29	1.38	56
May 27: Flower stalks surpassing basal leaves	1.42	.20	1.62	66
June 17: Flower stalks two-thirds grown	2.16	.05	2.21	90
July 6: Peak of flowering	2.39	.01	2.40	98
July 9: Flower stalks full grown	2.41	.01	2.42	99
July 18: Seed in milk	2.45	0	2.45	100

TREND IN FOOD RESERVES

The plant starts storing food reserves when it is about half grown and begins slowing in growth (fig. 2). From then on it makes more food than it uses in growth and respiration. The excess is stored. The plant maintains vigor by maintaining a normal supply of food reserves.

Approximately half of the seasonal stores are deposited by the time the shoot is 90-percent grown. In grasses and plants of similar growth development, this is about flowering time. Most of the reserves are deposited by the time the shoot is full grown, or at seed-ripe time in grasses. But reserves continue to accumulate for several days or weeks, while the plant still has greenness, until the amount of food made in photosynthesis just balances the amount used in respiration. Then reserves decline throughout the dormant period because of respiration, and continue to decline as growth resumes—until the shoot is about half grown—because of both growth and respiration. Reserves are lowest when the shoot is about half grown.

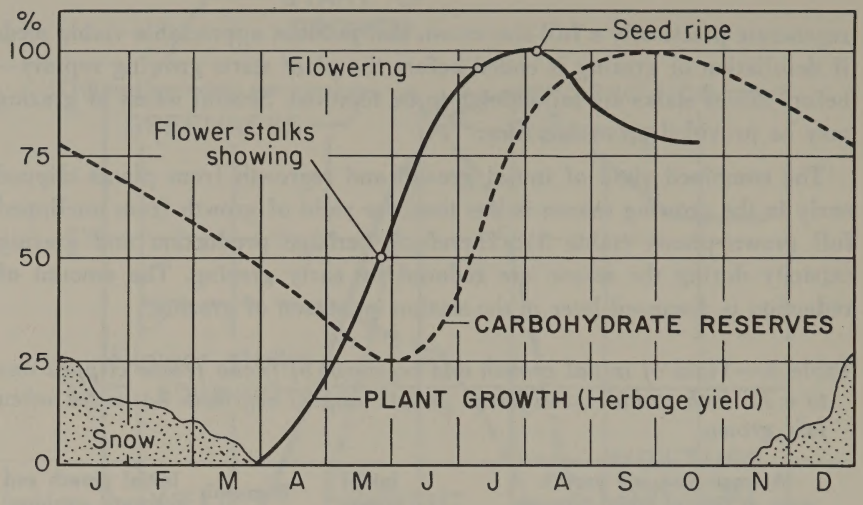


Figure 2.—Trend in carbohydrate reserves in relation to shoot growth. Shoot growth of Idaho fescue and based on data by Hormay and Talbot (1961). Carbohydrate curve, based on data by McCarty and Price (1951), is related to curve of Idaho fescue by plant growth stages.

EFFECT OF DEFOLIATION

Removal of the leaves of the plant anytime during the green period reduces the amount of food made and stored by the plant. As a result, the capacity of the plant to produce both shoot and root growth the next year is reduced. Defoliation is most harmful when reserves are lowest. This is about the time the plant is growing most rapidly.

However, defoliation of the plant anytime up to the time food storage is completed is harmful even at a relatively late growth stage (table 4). Plants vary in their ability to withstand defoliation. Wyethia, for example, withstands clipping better than other species because of greater food storage capacity and perhaps other reasons. Generally, close defoliation of the plant year after year—at almost any green growth stage—ultimately results in depletion of food reserves and the death of the plant.

Table 4.—*Change in size of four forage species clipped yearly to a 1.5-inch stubble at the seed-in-milk stage*

Year	Basal area				Fascicles[1]			
	Idaho fescue		Bottlebrush squirreltail		Longspur lupine		Woolly wyethia	
	Sq. in.	*Pct.*	*Sq. in.*	*Pct.*	*No.*	*Pct.*	*No.*	*Pct.*
1946	4.16	100	1.88	100	15.4	100	8.2	100
1947	2.16	52	2.22	118	5.0	32	7.7	94
1948	1.67	40	2.25	120	6.5	42	8.8	107
1949	1.39	33	.69	37	2.4	16	7.9	96
1950	.83	20	.71	38	1.4	9	6.9	84

[1] A fascicle is a group of leaves or leaves and stems that originate from a single bud.

Rhizomatous plants generally withstand grazing better than tufted plants. They are not grazed as completely because of their prostrate growth habit. They retain more greenness in the grazed-off stubble, and they usually have greater regrowth and food storage capacity.

The growth of herbaceous plants is not affected significantly by grazing after reserves are stored. The reserves and growing points on the plants are out of reach of animals. In woody plants, however, reserves and growing points are exposed, and grazing after reserves are stored and during the dormant period can harm these plants. Removal of growing points does the most damage.

The effect of defoliation is proportional to the amount of crown removed from the green plant. Studies show that 60 percent and more can be removed from some species without interfering with the future normal growth of the plant. Apparently, the plant can make adequate food with less than a normal size crown. The portion of the crown that can be removed safely is called the *proper-use amount.*

GRAZING MANAGEMENT

THE PROBLEM

High-level production of livestock and other values on western rangelands depends on the production of desirable, vigorous plants on the entire range. This can be accomplished mainly through proper management of livestock grazing.

The idea has long prevailed that overstocking is the main cause of range deterioration. This thought has been expressed as follows:

> White man allowed too many of his grazing animals to use the range. He overstocked the range almost from the start. How else explain the depletion of the range by more than half? (The Western Range, 1936).

This belief has led to a conviction that range improvement depends principally on regulation of stocking rate and that proper use of the vegetation can be obtained through proper stocking. This proper-use philosophy of management is more widely accepted today than any other and is the basis of management on most ranges.

However, assumption that plants can be grazed to a proper level through regulation of stocking is unrealistic because of the grazing habits of livestock. Livestock graze the range selectively, by species and areas. They consistently graze the more palatable plants and accessible areas closely and, invariably, beyond proper-use level. The pattern of use is very uneven, but much the same from year to year. Plants grazed closely one year tend to be grazed closely the next. So under continuous grazing at any stocking level, the more palatable and accessible plants are gradually killed out. Livestock then graze on less desirable plants. This process leads progressively to ever enlarging areas of deterioration. Unfortunately, the best plants and best grazing sites are destroyed first.

Destruction of the better plants and sites is accepted as inevitable under proper-use management:

> Just as there are certain sacrifice areas, there are also some sacrifice plants—species with high animal preference but never abundant in the stand. These "dessert" or "ice cream" plants are usually killed out when the hardier, more abundant, and somewhat less highly preferred key species are properly utilized, a fact that entails little economic loss. (Sampson, 1952).

The question may be asked: After the ice cream plants are destroyed what is sacrificed next? Clearly the degree of use on individual plants cannot be regulated.

The better forage plants and all others can be maintained, however, by periodically resting the range from use. Only by this means can the main objectives of grazing management—maximum production of vegetation and high-level yield of livestock and other multiple-use values—be realized.

REST-ROTATION GRAZING

Forage Production

To practice rest-rotation grazing management it is necessary to divide the range into pastures or units. Each pasture is systematically grazed and rested so as to provide for the production of livestock and other resource values and, at the same time, improve and maintain the vegetation and soil fertility. Maintenance and improvement of the resource is accomplished almost entirely by timely resting of the range from use. By dividing the range into pastures it is possible to graze a given number of livestock on the range each year.

Purpose of resting.—A pasture or unit of range is rested from use after a season of grazing to:

1. Allow plants opportunity to make and store food—to recover vigor.
2. Allow seed to ripen.
3. Allow seedlings to become established.
4. Allow litter to accumulate between plants.

The amount of rest needed for these purposes depends on the plants involved, character of the range, and objectives of management, so it is determined for each range individually.

Usually 1 or 2 years of rest is adequate to restore plant vigor. The key plant in deciding the amount of rest needed is the species that needs the most rest to regain vigor after it has been completely defoliated during the critical green period. Complete defoliation must be assumed because some plants are always grazed to this degree.

Seed-ripe date is determined by the species of plant that ripens seed latest in the season.

More than one year's rest is usually needed for establishment of seedlings. The key condition is that seedlings are large enough to withstand appreciable grazing and trampling. Usually this stage is reached after two seasons of root growth.

Accumulation of plant litter between plants is important in controlling soil erosion and improving soil fertility. Adequate litter usually accumulates during the rest periods provided for restoration of plant vigor and establishment of seedlings. However, in some cases special provision may have to be made for accumulation of a greater amount, for example, where soil erosion is a particular hazard.

Grazing formula.—The application of grazing-resting treatments to a range is outlined in a formula. A 5-treatment formula is illustrated (fig. 3).

This shows the order in which the planned grazing and resting treatments are applied in a pasture over time. The anticipated end results of such a sequence or cycle of treatments are high plant vigor, more plants, and more litter. Grazing after seed-ripe time in treatment *C* is very important in getting seedlings established because of trampling of seed into the soil. Seeds trampled in the soil, if only to a shallow depth, have a much better chance of germinating and establishing as seedlings than seeds that lodge on the soil surface, especially on eroded sites. The seeds should be trampled as soon as possible after falling so as to minimize loss to rodents, insects, and birds.

The sequence of treatments is repeated until the range is adequately vegetated. Then the range may again be grazed until the need for resting is again apparent. A certain amount of rest is always needed to maintain plant vigor.

The number of treatments in a formula depends on the amount of rest needed at various times. The number may be two or more but rarely exceeds eight. Many 3- and 4-treatment formulas have been worked out by range managers. A few 5-, 6-, and greater number-treatment formulas are in effect. The three treatments—*A*, *C*, and *D* in the 5-treatment formula illustrated—provide adequately for plant vigor, seed production, seedling establishment, and litter in many cases. But all these results cannot be realized with less than three treatments. Many different formulas can be developed with the same number but somewhat different treatments.

The range manager must prepare the formula to fit his specific range. The results obtained are determined by the formula. So grazing management is as effective as the manager makes it.

Number of pastures.—A pasture is needed for each treatment in the grazing formula. The number of pastures, therefore, is the same as the number of treatments.

The pastures should be about equal in grazing capacity. They may encompass any combination and proportion of vegetation types. On ranges with wide elevational differences, pastures should be laid out so about the same amount of low area is located in each.

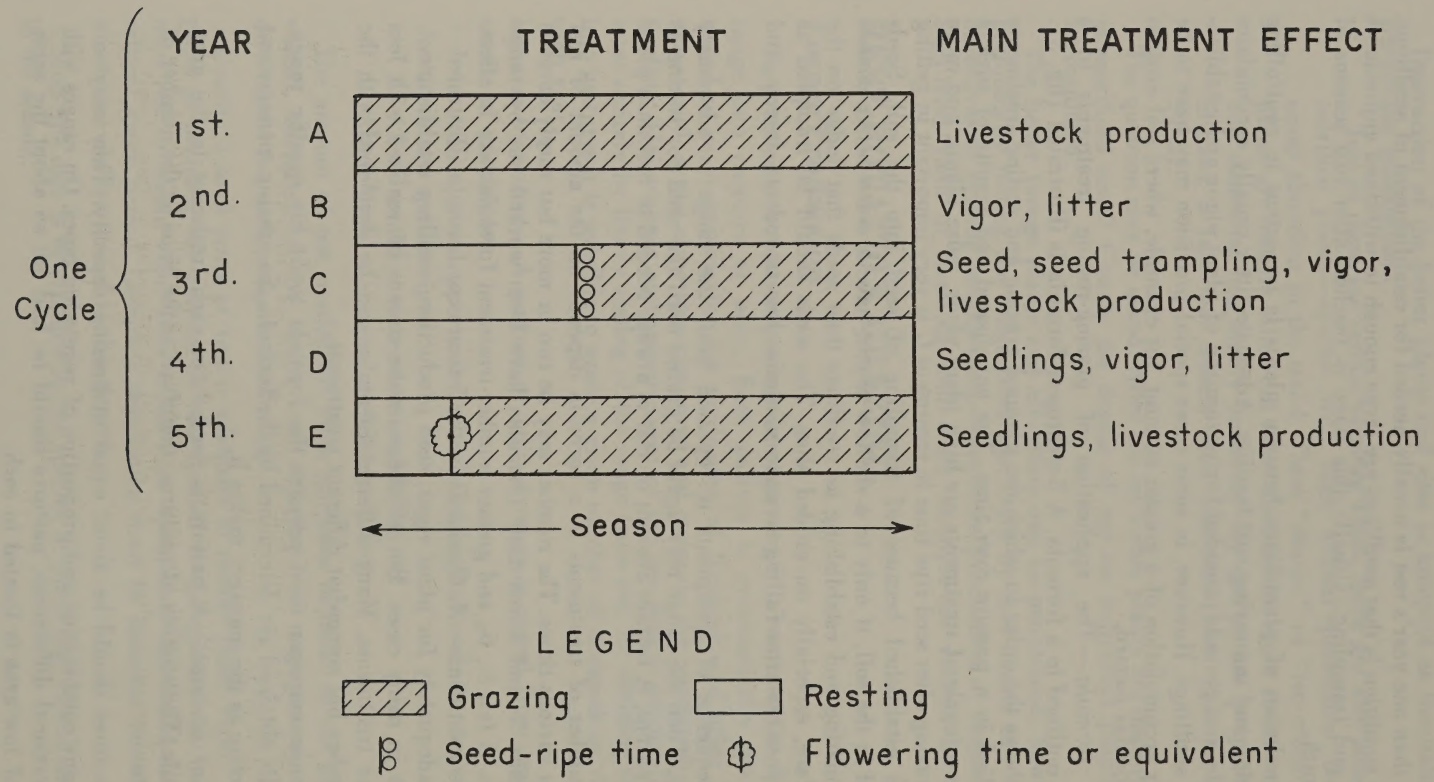


Figure 3.—A 5-treatment grazing formula.

Fencing is usually necessary on cattle ranges for adequate control of grazing. Usually it is not needed on sheep ranges where the sheep are herded.

Grazing schedule.—The treatments to be applied in each pasture can be programmed for several years ahead. A grazing schedule for a 5-treatment formula for a 10-year period is:

	Pastures				
Year	1	2	3	4	5
			Treatments		
1	A	B	C	D	E
2	B	C	D	E	A
3	C	D	E	A	B
4	D	E	A	B	C
5	E	A	B	C	D
6	A	B	C	D	E
7	B	C	D	E	A
8	C	D	E	A	B
9	D	E	A	B	C
10	E	A	B	C	D

Each pasture receives the treatments prescribed in the formula in order over time. Any treatment can be applied in any pasture the first year. Thereafter, the treatments are fixed. But they are changed when the formula is changed.

Notice that in the 5-treatment formula discussed here, 40 percent of the range area is rested from use each year and is thus reserved for other uses. The amount of area rested from use in well designed formulas usually ranges between 20 and 40 percent. But more may be rested to provide for special situations. The decision is up to the range manager. The vegetation in rested pastures is a form of insurance and may be grazed under adverse conditions, for example, in years of unusually low forage production.

Livestock Production

Stocking.—Under rest-rotation grazing, stocking rate is based on the forage that is produced on the portion of the range that is open for use each year. If livestock are not now being grazed on the range, forage production and stocking rate may be obtained by estimation, comparison with nearby ranges, or by a range survey. Surveys are the most time consuming. If livestock are being grazed, management may be started with existing numbers and then adjusted to the proper level.

Adequacy of stocking is determined by the performance of livestock and trend in the condition of the range. Stocking is adjusted upward or downward depending on responses. An effect of overstocking is most likely to show up first in livestock reactions—weight gains, reproduction, and health. Trend in range conditions is determined directly by observations of changes in vegetation and soil, rather than indirectly by observations on the degree of use of the vegetation.

It may take 3 or 4 years or even longer to arrive at a satisfactory stocking rate for the average year. During this period the grazing formula should be followed to the extent possible. But all pastures may be grazed if necessary under adverse conditions so as to minimize possible harmful effects to livestock. In this way, proper stocking is arrived at gradually and on the basis of actual use.

Season of grazing.—Under rest-rotation grazing, the range may be used any time of the year. Grazing may be started and ended anytime as determined by the range operator. However, it is highly desirable to have livestock on the range at seed-ripe time to trample seed.

The time when the season is started and ended has a bearing on both forage and livestock production during the season. For greatest livestock production, the grazing season should encompass the green period, when forage has high nutritive value (fig. 4). Plants produce greatest gains in livestock about the time they are growing most rapidly. Appreciable gains are made even on very young forage. High gains are made at seed-ripe time. Thereafter, gains decrease as the vegetation matures and dries, and nutrients —especially protein, starch and sugars, and vitamin A—become deficient. Late in the season livestock usually lose weight.

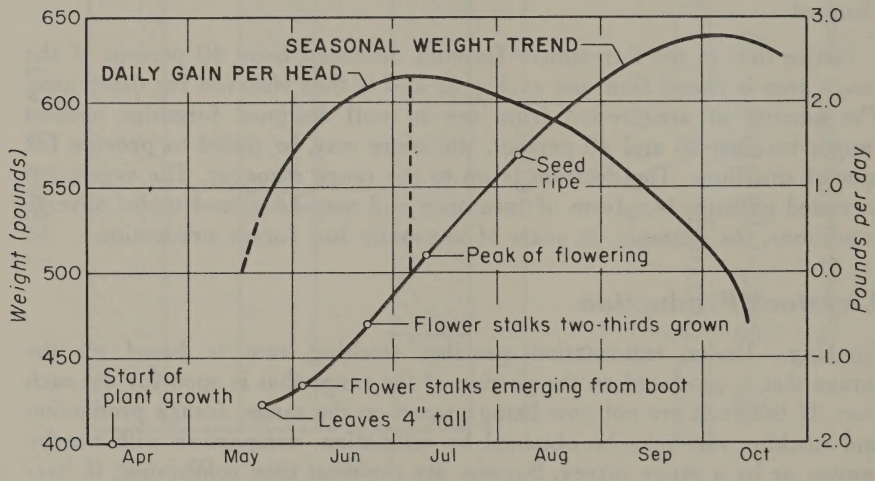


Figure 4.—Weight trend of yearling heifer in pine timber type in relation to growth in Idaho fescue. Based on data by Hormay and Talbot (1961).

The yield of livestock that may be expected from different seasons of the same length has been calculated for a bunchgrass range in California (table 5). The figures provide the livestock producer a basis for selecting a grazing season that best meets his needs. The absolute values in table 5 have significance only on the range studied in California. However, the relative difference in yield between different seasons has meaning anywhere when interpreted in terms of plant growth stages.

Table 5.—*Estimated cattle and forage production from various grazing seasons on a bunchgrass-type range, California, with forage use assumed to be 66 percent at end of season*

Beginning of grazing season and average growth stage of vegetation[1]	End of season	Cattle per section	Weight gain per animal	Cattle production per acre	Forage production per acre
2-Month Season					
		No.	*Pounds*	*Pounds*	*Pounds*
May 12: Flower stalks low in boot	July 10	98	116	17.8	193
May 22: Flower stalks in mid-boot	July 20	108	127	21.4	215
June 1: Flower stalks emerging from boot	July 30	117	131	23.9	231
June 11: Flower stalks one-third grown	Aug. 9	123	130	25	241
June 21: Flower stalks two-thirds grown	Aug. 19	125	124	24.2	245
July 1: Near flowering	Aug. 29	125	114	22.3	245
July 11: Just past peak of flowering	Sept. 8	123	100	19.2	244
July 21: Seed in milk	Sept. 18	122	84	16	240
3-Month Season					
April 22: Leaves about 2 inches tall	July 20	58	147	13.3	154
May 2: Leaves about 3 inches tall	July 30	65	166	16.9	172
May 12: Flower stalks low in boot	Aug. 9	71	178	19.7	190
May 22: Flower stalks in mid-boot	Aug. 19	76	182	21.6	203
June 1: Flower stalks emerging from boot	Aug. 29	79	177	21.8	213
June 11: Flower stalks one-third grown	Sept. 8	81	168	21.3	216
June 21: Flower stalks two-thirds grown	Sept. 18	81	155	19.6	217
July 1: Near flowering	Sept. 28	81	134	17	215
4-Month Season					
April 22: Leaves about 2 inches tall	Aug. 19	48	201	15.1	185
May 2: Leaves about 3 inches tall	Aug. 29	51	212	16.9	203
May 12: Flower stalks low in boot	Sept. 8	55	216	18.6	217
May 22: Flower stalks in mid-boot	Sept. 18	58	212	19.2	228
June 1: Flower stalks emerging from boot	Sept. 28	59	198	18.3	234
June 11: Flower stalks one-third grown	Oct. 8	60	178	16.7	236
June 21: Flower stalks two-thirds grown	Oct. 18	60	152	14.3	237

Table 5.—*Estimated cattle and forage production from various grazing seasons on a bunchgrass-type range, California, with forage use assumed to be 66 percent at end of season*—Continued

Beginning of grazing season and average growth stage of vegetation[1]	End of season	Cattle per section	Weight gain per animal	Cattle production per acre	Forage production per acre
5-Month Season					
		No.	*Pounds*	*Pounds*	*Pounds*
April 22: Leaves about 2 inches tall	Sept. 18	39	232	14.1	192
May 2: Leaves about 3 inches tall	Sept. 28	42	234	15.4	206
May 12: Flower stalks low in boot	Oct. 8	44	227	15.6	216
May 22: Flower stalks in mid-boot	Oct. 18	45	210	14.8	223

[1] In terms of Idaho fescue.

Livestock Handling and Distribution.—Under rest-rotation grazing two or more pastures are used during the season. However, from the standpoint of livestock production it is inadvisable to rotate the animals from pasture to pasture during the season. Under rangeland conditions livestock moved from pasture to pasture invariably gain less weight than livestock grazed continuously on one area. Adverse results are obtained even when the animals are moved onto ungrazed lush food. An example of such results was brought out in studies by Smoliak (1960). Other studies show similar results. All classes of animals are affected. So rotation of animals during the season is not advocated under rest-rotation grazing.

Undesirable results from moving animals come mainly from forcing the animals onto different feed and into new surroundings, and from denying them access to regrowth generated in pastures grazed earlier in the year. The latter point is most crucial.

Weight gains comparable to those under continuous grazing can be obtained under rest-rotation grazing by laying out fences, gates, and other management facilities with respect to topography, water, and natural routes of travel of the livestock so the livestock can move into new pastures by themselves. Gates are opened at the appropriate time. Under rest-rotation grazing, no attempt is made to graze the vegetation in any pasture or on the range as a whole to any particular degree. Livestock are turned loose to graze as they please once the pastures are opened to use. Notice that under the 5-treatment grazing formula outlined previously, all the livestock are confined in one pasture at the beginning of the season. At flowering, a second becomes available for use, and at seed-ripe time a third is opened. From then on all three pastures can be grazed to the end of the season. This mode of handling livestock on the range is a principal feature of rest-rotation and is exceedingly important in practical management. However, within limita-

tions of the grazing formula, the range operator may handle his stock any way he wishes. Herding animals about in pastures is not particularly harmful.

In rest-rotation grazing, salt is recognized as a food supplement. Place it where it will do the animals the most good. In some cases it may be used to get better utilization of forage. Put salt within easy reach of livestock, and on hard, unproductive ground if possible. Establish several licking stations on each salt ground to satisfy the animals and to spread and lighten soil trampling. If feasible, move salt grounds each year, if only a short distance. To reduce hazards to livestock and people, place salt a safe distance from roads.

Kind of livestock.—In rest-rotation grazing, the range may be grazed with any kind or combination of livestock that can be supported by the vegetation. Most efficient use of forage is made by grazing with more than one kind of animal.

Cultural Practices

Spraying, artificial seeding, and other vegetation treatments can be carried out in pastures without additional grazing controls or change in grazing plans. Treated areas can remain unfenced and can be any size and in any location in the pastures.

Spraying and comparable treatments are best applied in the pasture starting the longest rest period. Fall seeding is done in the pasture scheduled for seed trampling. Spring seeding is usually best done in the pasture scheduled for protection during the first-year growth of seedlings.

Before applying cultural treatments, manage the range for a few years to determine the exact need for the treatments. Then treat only the acreage required. In doing so, keep esthetic and all other multiple-use values in mind.

Certain herbicides can be used effectively to increase production of desirable forage by reducing competition from low-value plants. Users are cautioned to restrict their use of such materials to those registered for specific purposes or uses and to follow label instructions. It is also essential to provide for untreated zones and/or other safety practices to protect areas of human habitation, animals, streams, key wildlife areas, and other resource values and uses. (NOTE: Some States may have restrictions on the use of certain herbicides. Check your State and local regulations. Herbicide registrations are constantly reviewed by the U.S. Department of Agriculture. Consult proper authorities to be sure the intended use is still registered.)

In reseeding, avoid disturbing the soil by plowing or discing, if possible, to minimize soil erosion. Instead, try to drill directly into the existing plant cover either before or after plant competition is controlled by spraying. Generally, planting of several species in a mixture insures establishment of a stand. Conduct small tests of seeding, spraying, or other treatment before treating large areas in locations where data on soils, climate, etc. indicate site capability should be tested.

MANAGEMENT PRINCIPLES

Rest-rotation livestock grazing is a powerful tool available to the range manager for increasing land productivity. The prime force employed in this tool is resting. Its universal role in restoration of vegetation and land was expressed by the plant ecologist F. E. Clements (1949) as follows:

> From the very nature of climax and succession, development is immediately resumed when the *disturbing cause ceases*, and in this fact lies the basic principle of all restoration or rehabilitation.

The principle of resting may be applied in many forms of wildland management besides livestock grazing in which degree of use of the resource cannot be adequately controlled. For example, it may be applied in big-game grazing, harvesting of fish and game, management of stock driveways, and use of campgrounds, motor trails, and other sites.

Under rest-rotation grazing management, all plants—forbs, grasses, shrubs, and trees—are provided opportunity to grow and reproduce. So wildlife, recreation, watershed, and timber, as well as livestock interests, are served. Under a rest-rotation grazing plan designed to promote maximum livestock production, a substantial portion of the range is rested from livestock use each year and thus becomes available for other uses.

Flexibility in management is essential for good results. It is inherent in rest-rotation grazing management. Management is not spelled out in rigid form, but rather in terms of goals and plant and animal requirements. Good results in management are obtained through judicious application of knowledge of the resource and livestock by the range manager.

In rest-rotation grazing some or all of the rested pastures may be opened to use in years of critically low forage production. Pastures may be used ahead of schedule if necessary. The grazing formula may be compromised entirely in a given year; for example, this might be done when vegetation growth occurs only in some pastures during a year, as often happens in desert areas. More animals may be grazed in scheduled pastures in years of high forage production. In more normal years grazing is resumed according to formula and schedule.

Management ultimately rests with people immediately involved in the preparation and application of management plans. Good management depends on their knowledge and wisdom. Education and experience are equally important in gaining management facility. The key people in wildland management are stockmen, foresters, and such people in public agencies and departments as district rangers, area managers, wildlife managers, and range management advisers.

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